Upstream innovation leakage in Uganda’s coffee planting material pipeline

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Abstract

Policies and institutions shape the incentives that influence innovation, technology adoption and productivity. We characterise the robusta coffee planting material pipeline in Uganda that connects upstream innovation in improved germplasm to downstream coffee producers. A nationally representative survey of coffee nursery operators reveals poor and heterogeneous production practices, potentially reflecting shifting policy priorities. The majority of smallholder coffee farmers consequently get inferior, disease-prone seedlings—thereby locking in decades of continued low productivity. Given Uganda’s ambition to drastically increase coffee production, detecting, understanding and addressing these problems should be a top priority as a prerequisite to effective agricultural policy and enhanced productivity.

Keywords: robusta coffee, productivity, Uganda, innovation, nurseries, seed systems

JEL classification: D02, D22, Q12, Q18

1. Introduction

Coffee has long been the key cash crop and export commodity in the Ugandan agri-food sector. It has endured the booms and busts of the global coffee market and a devastating coffee wilt disease (CWD) outbreak in the late 1990s. Coffee yields continue to be low by international standards. Robusta coffee yields in Vietnam, for example, are on average 3–4 times larger than in Uganda. The prevalence of intercropping in Uganda explains some of this yield gap, but the quality, suitability and disease susceptibility of the robusta coffee varieties grown by Ugandan farmers also play a central role in stifling productivity
A recent, ongoing initiative to drastically expand the quantity of robusta coffee produced has thus far failed to address these quality concerns: Uganda is now blanketed with millions of new but inferior coffee trees that may perpetuate low productivity and high susceptibility for yet another generation of coffee farmers.

The coffee planting material pipeline (CPMP) in Uganda is currently riddled with problems, which presents clear upgrading opportunities. Ideally, the CPMP would convey high-quality planting material from upstream research institutes to coffee farmers while retaining as much as the production potential as possible. In practice, much of this production potential leaks out of the current CPMP in Uganda before reaching farmers, reducing the value added of the coffee sector. With each newly transplanted seedling, farmers lock in lower production potential for decades to come. Furthermore, farmers may rationally underinvest in newly transplanted seedlings that are weak, low yielding and disease prone. As is true with planting material in other agricultural contexts, there can be strong complementarities between the input investments (i.e. fertiliser, pesticides, and agronomic practices) and the innate production potential of new coffee trees: vigorous trees with disease-resistant germplasm can respond more and more reliably to other inputs and thereby encourage farmers to invest more intensively in enhanced productivity. In contrast, weak, disease-susceptible trees can lower the return on and increase the risk of such investments.

Our analysis aims to provide specific insight into the functioning of the Ugandan coffee sector from an Innovation Systems perspective, emphasising how institutions and their embeddedness and interactions in broader systems shape the emergence and evolution of innovation (Freeman, 1987; Dosi et al., 1988; Lundvall, 1992; Nelson and Rosenberg, 1993), which—consequently—is typically non-linear and path dependent. Applied to agriculture, this approach incorporates distinctive features of innovation in the agri-food sector, namely, its heavy reliance on upstream public investments and institutions with important intermediary and downstream roles played by the private sector (Spielman, Ekboir and Davis, 2009; Klerkx, van Mierlo and Leeuwis, 2012). In low- and middle-income countries (LMICs), public sector entities often critically shape the enabling environment that encourage or discourage agricultural innovation. This influence can be direct and explicit (e.g. funding basic or applied science through competitive grants programmes) or indirect and subtle (e.g. regulation or education policies that direct how entrepreneurs, producers and workers engage in agricultural value chains). If the processes that govern the emergence of new policies, regulations or enforcement are static and unresponsive, innovation may be stifled or slowed. If instead the policy processes are dynamic and responsive, public governance of value chains is more likely to successfully create an enabling environment that encourages innovation and technology adoption and, ultimately, stimulates innovation-based growth (Klerkx, van Mierlo and Leeuwis, 2012; Mekonnen et al., 2015).
From this Innovation Systems perspective, leakage throughout the CPMP is but one manifestation of how supply chain regulation, market performance and other key dimensions of the enabling environment shape the impact innovation has on the agri-food sector and economic development more generally (Murphy, 2007; Larsen, Kim and Theus, 2009; Zilberman et al., 2022). The upgrading of agri-food value chains, often facilitated by the public sector, is enabled by the adaptation and adoption of new technology (Webber and Labaste, 2010). In this broader context, the institutional and policy dynamics of the CPMP in Uganda determine whether upstream technological advances (e.g. breeding for CWD resistance, tissue culture methods) translate into realised productivity gains among producers and added value throughout the sector. While this paper aims to enhance our understanding of how public sector engagement and regulation shape innovation and productivity, our specific focus is on an understudied component of the agricultural innovation system: upstream planting material multiplication.

While the functioning of seed systems in LMICs has been the subject of research attention from a variety of disciplinary perspectives (e.g. Louwaars and de Boef, 2012), there is much less known about systems that provide vegetatively propagated planting material in these contexts (for a rare recent exploration, see Spielman et al., 2021). The closest published analysis to ours documents recent upgrading and productivity gains throughout the Ethiopian coffee sector and, incidentally, finds that a general lack of planting material of a reliable quality remains a binding constraint in this critical value chain (Minten et al., 2019). We build on this study with a sharper focus on the specific leaks in the CPMP that limit the impact of innovation in coffee planting material that has emerged in the national agricultural research system in Uganda. As a result of this considerable leakage, we argue that the realised productivity of the majority of Ugandan coffee producers is a tiny trickle of what it otherwise could be.

In this paper, we use a detailed survey conducted with coffee nursery operators (CNOs) throughout Uganda to shed new light on this important but largely overlooked ‘seed’ system in the hopes of encouraging future research. We find three distinct clusters of coffee nurseries, two of which adopt very few best production practices. While the third cluster invests in best practices and produces quality planting material, even these seedlings are mostly not disease resistant. The highest-quality seedlings are produced clonally by in-house nurseries affiliated with large private coffee estates and are disease resistant but are effectively inaccessible to the vast majority of Uganda’s smallholder coffee farmers, who are stuck with inferior subsidised seedlings and therefore paltry productivity. On the basis of these conceptual and descriptive insights, we discuss institutional and policy priorities that might help to fix these leaks and retain greater value in the Uganda coffee sector.

The time for seriously considering these innovation opportunities has never been better given the ambitions of the Government of Uganda to increase national coffee production by over 500 per cent by 2030. The realisation of any such ambition will demand dramatic enhancements to the CPMP, including
focused upgrading efforts and investments to build nurseries’ capacity to produce higher-quality material and farmers’ willingness to pay for better planting material. In this undertaking, the public institutions that oversee and regulate the CPMP could learn important lessons from the private coffee estates in Uganda that have of necessity created their own in-house nursery capacity.

2. Robusta coffee production in Uganda

Coffee epitomises both the importance and the low productivity of agriculture in Uganda. It supports the livelihoods of millions of smallholder farmers, processors and intermediaries. As one of the Africa’s largest coffee exporters, Uganda also ranks among the top coffee exporters in the world. These coffee exports are a matter of national macroeconomic importance as they generate nearly 20 per cent of all foreign exchange in the economy (AMA, 2015).

Uganda has a history of public investments in upstream coffee research and the coffee sector via two public institutions: the National Coffee Research Institute (NaCORI)\(^1\) and the Ugandan Coffee Development Authority (UCDA).\(^2\) In response to the devastating CWD outbreak in the 1990s, the NaCORI developed seven lines of CWD-resistant (CWD-r) robusta planting material. These lines were identified, developed and partially approved for distribution by 2006. The UCDA is responsible for coordinating, overseeing and promoting the entire coffee value chain in Uganda. The UCDA disseminates coffee planting material through a vast network of CNOs; trains, registers and periodically inspects these CNOs and directly procures the planting material produced by these CNOs and coordinates the distribution of this material to coffee farmers via the National Agricultural Advisory Services (NAADS) and more recently through ‘Operation Wealth Creation’ (OWC), which is now the main channel for sourcing and distributing agricultural inputs including coffee planting material. The UCDA, however, continues to orchestrate the CPMP as a meta-intermediary that aims to link NaCORI planting material to Ugandan coffee farmers, a status further expanded in the National Coffee Bill 2018 that aims to consolidate responsibility for both on- and off-farm coffee activities under the UCDA.\(^3\)

As an integral part of the national strategic plan for agriculture (MAAIF, 2016), the President’s Coffee 2020 Plan (subsequently rebranded 2030) has changed the coffee industry and institutions in Uganda via ambitious targets to rapidly expand coffee production throughout the country.\(^4\)

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\(^1\) NaCORI is one of the 16 Public Agricultural Research Institutes formed under the National Agricultural Research Organization (NARO). Although coffee research has long been a mainstay of NARO, NaCORI was created in its current institutional form in 2014 as part of the National Coffee Policy. For simplicity, this report will refer to its predecessors as NaCORI even though the official name of the institute has changed over time.

\(^2\) The UCDA was established by the Ugandan Parliament in 1991 and charged with promoting and overseeing the coffee industry in Uganda (see https://ugandacoffee.go.ug/about-ucda) (Accessed 3 July 2020).

\(^3\) This Bill was passed by the Ugandan Parliament in 2020.

\(^4\) Originally, this plan set an entirely implausible target of increasing production by 500 per cent—from 3.5 million (60 kg) bags in 2015 to 20 million bags by 2020. This goal has also been
McKinsey created a medium-to-long-term ‘Coffee Lab’ road map for achieving this goal, which identified several initiatives to enable this massive replanting and extensive margin expansion of coffee production (see Supplementary Table A2). \(^5\) Most recently, the Government signed a controversial agreement with an Italian company that gives it exclusive rights to export all Uganda coffee in the hopes of fuelling its production of 20 million bags by 2030.\(^6\)

The UCDA issues detailed monthly reports for the Uganda coffee industry. According to its November 2017 report,\(^7\) there were a total of 2,089 coffee nurseries in Uganda—a dramatic expansion from the 1,138 nurseries reported a few years earlier (AMA, 2015). This report estimates that these nurseries have over 157 million seedlings available for transplanting, 118.3 million of which have been planted. In stark contrast, in 2011/2012, the total seedling production in Uganda stood at 18.6 million. This massive, nearly 10-fold expansion in the volume of planting material moving through the Ugandan CPMP began before the 2015 launch of the Coffee 2020 Plan but has been fuelled by the plan in recent years. Based on the UCDA export data for April 2020, a total of 359,973 bags were exported in the month of April.\(^8\) The March 2020 report noted that 4.88 million bags were exported for the period April 2019–March 2020, which is far below the estimated 20 million bags per year by 2020.\(^9\) Despite COVID-19 disruptions, Uganda’s export increased from 5.65 million bags for the period April 2020–March 2021 to 6.52 million bags for the period April 2021–March 2022.\(^10\)

Supplementary Table A1 provides an overview of key historic events in the Uganda coffee subsector, especially as related to the CPMP (see AMA, 2015). By far, the most notable event in the modern history of the CPMP in Uganda was the CWD outbreak of the 1990s, which decimated 45 per cent of all coffee trees in Uganda and sent shockwaves through the subsector (see Rutherford, 2006). To appreciate the impacts and implications of the CWD outbreak, it more realistically modified to achieve this fivefold increase in production by 2025 and, more recently (and realistically) still, by 2030 (see https://ugandacoffee.go.ug/genesis-coffee-roadmap and http://allafrica.com/stories/201710300123.html) (Accessed 3 July 2020).

5 Among these transformative initiatives, one directly (number 7) and two indirectly (number 5 and number 6) relate to the CPMP. The directly related initiative number 7 suggests a clear recognition of the importance of a CPMP that supplies high-quality planting material of improved coffee varieties. The indirectly related initiatives both invoke ‘extensive margin’ increases in coffee production by bringing ‘underutilised’ land into production. These extensive margin initiatives could be supplied with planting material by simply scaling up the current CPMP to generate a greater volume of planting material, but they would be far more effective if they were combined with initiative number 7 so that this expansion in area devoted to coffee was paired with significant ‘intensive margin’ gains due to improved planting material.


is important to understand the distinction between seedlings, (clonal) cuttings and (clonal tissue culture) plantlets, the types of robusta coffee planting material that co-exist in the Uganda CPMP:

(i) ‘Seedlings’ are grown from coffee seed. Ideally, this seed is produced as ‘elite’ seed from dedicated seed producers with direct access to approved NaCORI coffee varieties, but it is just as easy to grow seedlings from ‘local’ seed of unknown origin.\(^\text{11}\) Ninety-five per cent of robusta coffee planting material in Uganda consists of seedlings (AMA, 2015).

(ii) ‘Clonal Cuttings’ are propagated from nodal cuttings of existing coffee trees. Ideally, these trees are specifically maintained as a ‘mother garden’ based on material provided directly from the NaCORI. Cuttings are more difficult to propagate than seedlings and have a lower transplanting success rate, but as clones they retain the germplasm of the mother garden tree.\(^\text{12}\) Most notably, the seven CWD-r varieties developed by the NaCORI in response to the CWD outbreak only retain their disease-resistant properties when they are propagated clonally via cuttings. If they are propagated by seed, the genetic purity of these lines quickly erodes and, along with it, the disease resistance.\(^\text{13}\) It is estimated that only 5 per cent of the official UCDA-registered robusta CPMP consists of cuttings (AMA, 2015).

(iii) ‘Clonal Tissue Culture Plantlets’ are propagated \textit{in vitro} in modern tissue culture laboratories from healthy leaves of a mother plant that has desirable genetic properties. Because these are clones like clonal cuttings, they retain the full CWD-r attributes if drawn from one of the CWD-r lines from the NaCORI. Unlike cuttings, the leaf and root structure of these plantlets is indistinguishable from seedlings. The primary advantage of tissue culture plantlets is that they are propagated in controlled and clean conditions, which eliminates the risk of contamination through inferior or diseased soil, polybags or water. Ideally, these plantlets would be used as mother gardens to produce superior cuttings to be distributed to farmers. In the current CPMP, only advanced coffee estates have access to plantlets of this type—typically via in-house nurseries with access to private tissue culture facilities via contract.

After the NaCORI developed the seven lines of CWD-r planting material, the UCDA shifted its focus to training up a new generation of CNOs that could properly propagate clonal cuttings via mother gardens in order to

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\(^\text{11}\) Robusta coffee is endemic to Uganda and so is well adapted to the local agro-ecological conditions. This means that growing seedlings from seed is remarkably easy.

\(^\text{12}\) In addition, clonal cuttings can mature more quickly into fruit bearing trees, which reduces the time to first harvest for farmers. See, for example, http://www.monitor.co.ug/Magazines/Farming/growing-klonal-Robusta-coffee-paying/689860-280844-12cibh7z/index.html. (Accessed 3 July 2020).

\(^\text{13}\) In the case of hybrid coffee varieties, clonal cuttings ensure that the hybrid vigour is fully transmitted to the first-generation planting material farmers transplant into their fields; if these are instead grown from seed, farmers end up transplanting second- (or, worse, third-) generation material that lacks this hybrid vigour.
retain the full CWD-r properties of this material. Since the CWD outbreak and ensuing destruction were still evident at that point, this push to establish a new, more sophisticated, more resilient CPMP was natural—but frustrations quickly ensued. The NaCORI did not yet have in-house tissue culture facilities and instead focused on scaling up the CWD-r material via clonal cuttings, which can be a slow process. In the end, the volume of clonal cuttings distributed across the country for mother gardens was tiny and fell far short of what was needed to fill the CPMP with high-quality, CWD-r cuttings.

The launch of the President's Coffee 2020 Plan in 2015 came after several such years of frustration and evidence that promising CWD-r material (and other inputs (e.g. fertiliser and irrigation)) was not reaching farmers. This ambitious plan set the UCDA into overdrive to rapidly expand the volume of seedlings being multiplied and distributed through the CPMP, marking a clear shift towards quantity and away from quality in the CPMP. Volume quickly became the top priority—and the memory of the CWD devastation of the 1990s seemed to fade.

3. Conceptual framework: CPMP

Our focus on the CPMP for robusta coffee is essentially a stress test of the pipeline that is tasked with delivering planting material to farmers. Based on what we can know or infer about the current CPMP, is this pipeline up to the task? What major leaks in the pipeline prevent the full production value of coffee planting material from being delivered intact to farmers? The biggest leakages represent the biggest policy opportunities to retain value and achieve productivity gains in the coming years. In this section, we lay out key assumptions and elements of the CPMP as a conceptual framework. We focus on robusta coffee exclusively. We take the upstream R&D investments at the NaCORI (e.g. development of CWD-r material, other disease resistance and breeding work) as given. Thus, we do not evaluate the institutional structure, incentives or innovation efficiency of the NaCORI but simply take this as the ‘headwaters’ for the CPMP in Uganda. We focus how well this material is disseminated to farmers.

After farmers receive material from this pipeline, many other constraints create additional downstream ‘leaks’ in the coffee subsector. For example, official reports from 2016 suggest that the overall survival rate of seedlings delivered to farmers via OWC was roughly 36 per cent with over 40 million seedlings perishing between procurement at the CNOs and farmers’ fields. On-farm, there is similarly a host of constraints that reduce the productivity of coffee trees, including suboptimal agronomic and pruning practices, insufficient or non-existent investments in fertiliser, pesticides or other inputs; biotic stresses such as CWD and coffee twig borer; abiotic stresses such as poor

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14 An internal (unpublished) UCDA report indicated that 64.5 million seedlings were procured from September 2015 to May 2016, of which only 54.6 million were delivered to farmers. Only 36 per cent of the total amount procured had survived distribution and were still alive when post-distribution surveys were conducted in the second half of 2016. The survival rate based on maturity to producing coffee trees will likely be yet lower.
soils and drought (see Wang, 2014). Additional constraints arise after the farm gate—as coffee berries are purchased and processed in the downstream value chain. While these constraints all matter enormously to the value added (and retained) along the coffee value chain, they are not our focus in this study. We acknowledge their presence and importance but focus our attention here on the CPMP that delivers planting material from the gates of the NaCORI to Ugandan coffee farmers.

One reason to focus on the CPMP is that the productivity limits of planting material as it emerges from the pipeline and is transplanted are largely set for remaining life of the coffee tree. The critical interactions of Genetics, Environment and Management (GxE) shape the realised productivity of the tree, but material that is genetically inferior or diseased at transplanting is likely to have reduced productivity across its lifespan, which we assume to be 20 years. Although environmental and management factors (e.g. rehabilitation through careful agronomic practices, appropriate input investments, weather and pest pressure) can partly offset these initial deficiencies, genetics provide an essential foundation for future productivity investments.

The influence of GxE pertains to CNOs who produce planting material just like it does to coffee farmers. Enhanced production potential hinges on genetics via improved germplasm, including elite seedlings propagated directly from elite seeds from NaCORI planting material and (better still) clonal propagation of cuttings or plantlets to retain CWD-r and hybrid vigour. However, the effects of and interactions with the E and M of nurseries also shape the health and phytosanitary vigour of planting material via clean propagation conditions and investments in best practices and quality inputs (soil, water, etc.).

Although the CPMP explicitly refers to the flow of planting material, the flow of information about specific quality dimensions of planting material crucially determines the incentives that prevail along the pipeline and, consequently, how well it functions. In the current structure of the CPMP in Uganda, the UCDA influences how and how much information flows through the pipeline and the incentives faced by CNOs and other actors. For most CNOs, the customer of choice—indeed, the only viable customer for many—is the UCDA itself. Thus, the procurement policies of the UCDA most directly affect the decisions made by CNOs.

Until 2017, UCDA’s official procurement price for elite seedlings was 300 UGX/seedling. In late 2017, the UCDA posted updated prices on their website as follows: 350 UGX for elite seedlings, 1,000 UGX for clonal cuttings and 1,500 UGX for tissue culture plantlets. While it is not clear how and how many cuttings and plantlets the UCDA procures at these prices, those familiar with the system expect that at least 90 per cent or more of the material procured and distributed via OWC consists of elite seedlings. Moreover, while the UCDA conducts periodic inspections of nurseries, it is not clear what specific information is collected in these inspections and how it is conveyed, if

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at all, to farmers or other downstream actors in the pipeline. Some characteristics of a seedling are readily observable to farmers, including number and colour of leaves and whether it was propagated from a clonal cutting. Other key attributes are not observable—either to farmers or UCDA inspectors—including CWD resistance, hybrid vigour and whether a seedling is a tissue culture plantlet or a seedling. Certainly, the UCDA has other means of inferring the quality of planting material produced by nurseries, but it is less clear how much of this information is transmitted up and down the pipeline and whether the incentives of key actors align with information transmission.

The fact that some quality attributes are not directly observable raises important challenges. As a complicating factor, some claim that smallholder coffee farmers do not know enough about these important attributes to even try to discern these dimensions of quality (Brandi et al., 2007; Derero, 2012). While there are surely some discriminating and clever farmers who understand how unwise it is to commit decades of care and maintenance to a new seedling of questionable provenance and quality, it seems likely that the average smallholder coffee farmer is now little more than a passive recipient of a free OWC seedlings procured from nurseries that have passed the UCDA’s inspection. In contrast, there are some very large, sophisticated coffee producer exporters in Uganda that understand perfectly the importance of getting high-quality planting material. These producers would never consider investing in seedlings of unknown provenance and quality. They recognise the magnitude of the G risks of procuring seedlings from independent CNOs or from the UCDA given their substantial investments in E and M. Many such growers have vertically integrated nursery operations in order to exert much greater control over the full scope of GxExM interactions. Given their persistent concerns about CWD susceptibility, they procure CWD-r material directly from the NaCORI and propagate tissue culture plantlets or clonal cuttings under carefully controlled and clean conditions.

To illustrate the durability of potential seedling deficiencies and highlight the significant implications of this durability for the expected value of lifetime production of a coffee tree, we construct a simple simulation of expected yields in coffee cherries. Simulating yields in terms of unprocessed harvested cherries, called Kiboko in Uganda, simplifies the simulation and focuses this simple analysis on production potential without accounting for post-harvest value addition.
coffee trees. While these are simple stylised simulations, they underscore the potential magnitude of losses due to $G\times ExM$ interactions that lead to chronic yield deficits and susceptibility to CWD.

4. Empirical analysis and results

4.1. CNO sample and survey

To understand the current constraints and opportunities in the robusta CPMP, we conducted a detailed survey of CNOs. To finalise the sampling frame and questionnaire, we first conducted a series of key informant interviews with actors throughout the CPMP and collected and reviewed relevant pre-existing studies from the Ugandan coffee industry. In this section, we describe the sampling frame and questionnaire we designed to collect data from CNOs.

We constructed our sampling frame around three regions of Uganda with significant robusta coffee production: Western, Central and Eastern. In each of these regions, we consulted with local UCDA representatives to select four or five robusta coffee growing districts. For each of these four target districts, we then acquired a list of all UCDA-registered CNOs. From these lists of CNOs, we randomly selected CNOs to interview. To complement this sample of UCDA-registered CNOs, our research team specifically sought unregistered CNOs to add to the sample. There were very few such ‘informal’ CNOs in these target districts, so we ended up with only 13 unregistered CNOs in our sample. Our final sample consists of 178 CNOs spread across 14 districts. The location of these sampled CNOs is depicted in Figure 1. Approximately 75 per cent of these sampled nurseries are individual operations; the remaining nurseries are a mix of family, group and association operations. About two-thirds of our respondents are owners of the operation, and the remaining third are managers and employees of the nursery.

The questionnaire was designed to capture important dimensions of heterogeneity among CNOs, including the size, age, cost structure, planting material sources and customers of the nurseries. In the survey, CNOs identified their biggest challenges and responded to several questions about ‘best practices’ to serve as a proxy for both the knowledge of CNOs and the quality of the planting material they produce. We asked several questions about financing of nursery operations and the personal wealth level of CNOs.

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17 As discussed in Supplementary Appendix A, these expected present values do not account for higher planting material costs of high-quality CWD-r seedlings, but even if they increased seedling cost by 500 per cent, the expected net present value would be over 9,000 UGX per seedling.

18 Supplementary Figure A1 shows the frequency of responses to an open-ended question about the biggest challenges of operating a coffee nursery.

19 This research was approved by the University of California, Davis Institutional Review Board (UC Davis IRB). Upon review of the application for IRB approval, the UC Davis IRB designated the research ‘exempt’ as the questions were considered to be non-invasive, non-threatening and non-sensitive. The research was also granted research authorisation from Uganda National Council for Science and Technology (UNCST).
Fig. 1. Map of Uganda with location of surveyed CNOs, which were randomly sampled from a complete census of registered CNOs and constructed list of informal (unregistered) nurseries.

4.2. Identifying clusters of robusta coffee nurseries

One of our primary objectives in conducting this CNO survey is to better understand the heterogeneity among CNOs in order to more clearly identify potential ‘leaks’ in the CPMP that reduce the potential production value delivered to farmers. We begin by exploring self-reported adherence to ‘best practices,’ which we use to construct a best practices index. We then combine this best practice index with several other relevant characteristics of CNOs and conduct a cluster analysis in order to identify groups of CNOs in our sample that share important structural features. With these clusters identified and defined, we then contrast and compare these clusters along several dimensions.

The ‘best practices’ module contains 29 questions, which were formulated and vetted with assistance from coffee agronomists. We use a subset of these questions to formulate a factor analytic index of best practices. The resulting index provides a data-weighted index of best practices for each CNO that
serves as a useful proxy for the general propagation conditions of the nursery and for the phytosanitary health and vigour of planting material produced by the nursery. By construction, this index has a mean of zero across all CNOs in the sample. Supplementary Figure A2 shows the distribution of this best practices index across these nurseries. Most nurseries follow very few of the best practices embedded in this subset of questions and, consequently, have best practice indexes below zero. Among those that adopt some of the practices, there is a range of best practice adoption that spans the right side of the distribution, with a clear and distinctive group of CNOs that maintain relatively good practices. In our continued analysis in this section, we aim to identify these nurseries as they are much more likely to produce quality seedlings. That is, they are less likely to lose potential production value via inferior propagation practices.

To explicitly identify groups of like nurseries, we use cluster analysis using seven predefined characteristics of nurseries. These clustering variables along with the breakdown in median values across the three resulting clusters are shown in Table 1. The spatial distribution of these three types of nurseries is shown in the map in Figure 1. Based on the observable differences across these groupings of nurseries, we qualitatively describe these three clusters as follows:

(i) **Cluster 1 ‘Small, low-input nurseries using family labour and very poor practices’**: These 24 nurseries score very low on the best practices index and employ family labour for the majority of the work around the nursery. They are slightly more likely to use female labour. They are the smallest of the three clusters and invest only lightly in chemical and fertiliser inputs. These nurseries appear to correspond quite well to the low-input low-cost nursery model described in Mbwoa et al. (2014). Cluster 1 nurseries produce 11 per cent of the total seedlings produced by our CNO sample.

(ii) **Cluster 2 ‘Larger, medium-input nurseries using poor practices’**: This cluster of 95 nurseries is the largest of the three. They score slightly better on the best practices index but in absolute terms still do poorly in this regard. They are no more likely to be connected to other CNOs than Cluster 1 nurseries, but are much larger, employ hired labour and invest more in chemical and fertiliser inputs. Overall, these nurseries appear to be larger and more formal versions of Cluster 1 nurseries. Cluster 2 nurseries produce 60 per cent of the total seedlings produced by our CNO sample.

(iii) **Cluster 3 ‘Large, high-input, well-connected nurseries using good practices’**: These 36 nurseries clearly stand out from their Cluster 1 and 2 counterparts. In particular, they score much higher on the best practices index, are much more integrated into local CNO networks, invest much more in purchased inputs and produce more seedlings than the

20 We conduct this using a comparison of median values of these seven variables rather than of mean values to limit the influence of potential outliers in the data.
other two clusters. If high-quality planting material is likely to emerge from the current CPMP via UCDA-registered nurseries, it is almost certainly going to emanate from these Cluster 3 nurseries, which produce 29 per cent of the total seedlings in our sample.
The assessment of propagation practices is central to how the heterogeneity in the CPMP translates into the retention of production value potential. The cluster analysis only uses relative differences in these best practices between different CNOs. We also care about the absolute extent of best practice adoption. In Table 1, we show the average ‘yes’ response to a selection of best practices. While Cluster 3 nurseries clearly have better propagation practices, adherence with best practices falls well short of complete even among these higher-quality CNOs.

4.3. Cluster heterogeneity among robusta coffee nurseries

Now that we have well-defined clusters of nurseries that share essential characteristics, we delve deeper into dimensions of heterogeneity. Although descriptive and exploratory in nature, this analysis provides some key insight into the functioning and structure of the current robusta CPMP. Since so much of planting material quality—including, CWD-r—hinges on clonal propagation of cuttings from a mother garden, we first look at the prevalence of established mother gardens by cluster.

Table 1 shows that while 42 per cent of nurseries in Cluster 3 reported having a mother garden, very few in Clusters 1 and 2 have one. Table 1 also shows a clear (and related) pattern in the age of the nursery: Cluster 3 is the most established of the three types. Taken together, these patterns seem to corroborate the evolution of the UCDA priorities with respect to the CPMP over the past decade. At the time that Cluster 3 nurseries were being formed, the UCDA was trying to expand the capacity of the CPMP to create clonal cuttings in order to ensure the diffusion of CWD-r planting material. As frustration set in over the difficulty of this approach and the pressure to dramatically expand coffee production mounted, the UCDA shifted its focus to volume of coffee seedlings produced by the CPMP. While other explanations may also have merit, this shift is consistent with patterns seen in the clusters of nurseries in our sample.

Not surprisingly, Cluster 3 CNOs that are more likely to have a mother garden are more likely to pay attention to the source material they use in their nursery. Specifically, we find that while 94 per cent of Cluster 3 CNOs always seek out specific source material, only 74 per cent of Cluster 2 CNOs do (with the other 26 per cent taking whatever they can get). As a result of these mother garden capacity constraints and related differences between these clusters, less than 13 per cent of the planting materials produced in our sample are clonal cuttings. This implies that at most 13 per cent of the planting material from

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21 In particular, one explanation could be that Cluster 3 CNOs are further along a learning curve and that Cluster 2 and 1 CNOs will follow suit if given sufficient time to mature and learn best practices, etc. As addressed later, we do not think that this is as credible an explanation and believe instead that the selection of CNOs being drawn into nursery management has changed substantially with UCDA priorities.

22 Without disaggregating by cluster, we find that nurseries with mother gardens are on average older (11.4 years in operation) than those without mother garden (4.6 years in operation), which is similarly consistent with UCDA training and registering CNOs under different objectives and criteria a decade or more ago.
our sample nurseries is resistant to CWD, leaving an astounding 87 per cent of the CPMP susceptible to the disease.

Next, we consider the quality of the water source used to irrigate the planting material in the nursery—disaggregated by cluster. Since the two most important sources of contamination and disease in a coffee nursery are soil and water, this has a direct and important effect on phytosanitary health and vigour of the planting material. As shown in Table 1, there is a clear difference in water source and usage across our three clusters. We find that Cluster 3 CNOs use significantly less water than their Cluster 1 and 2 counterparts and that the water they use is much more likely to be from a high-quality source. More specifically, 58 per cent and 65 per cent of water used by Cluster 1 and 2 nurseries, respectively, comes from low-quality sources (i.e. stagnant or open water sources). In contrast, 43 per cent of water in Cluster 3 nurseries is low quality.

Table 1 shows that all three clusters tap personal savings with considerable frequency to finance their operations. While nearly 90 per cent of Cluster 3 nurseries use personal savings in this way, Cluster 1 nurseries are not far behind at 77 per cent. Although fewer rely on formal loans from banks or other credit institutions to finance their nursery operations and Cluster 3 nurseries use credit with greater frequency, they are not that different than their Cluster 1 and 2 counterparts.

Since these nurseries tend to be individual operations, the wealth level of the CNO can have a significant impact on how well capitalised the nursery is. For the two-thirds of respondents who are CNOs, we collected detailed asset data and other wealth indicators (e.g. access to remittances). We use these variables to construct a factor analytic wealth index (similar to the best practices index above). We graph the cumulative distribution of this wealth index for each cluster separately in Figure 2. Generally, Cluster 3 CNOs are wealthier than Cluster 2 CNOs, who are wealthier than Cluster 1 CNOs. This includes some Cluster 3 CNOs who are quite wealthy in relative terms (e.g. wealth index > 2). Here, we explore heterogeneity between the CNOs in different clusters in more detail then discuss implications of this structural heterogeneity for CPMP policy, operation and efficiency.

Figure 3 depicts the cost structure of nurseries by cluster. The composition of the labour force (panel (a)) employed by these different nurseries is quite distinct in Cluster 1, which relies more heavily on family labour than either Cluster 2 or 3. In panel (b), we see that the general breakdown of costs is remarkably similar across the three clusters. In panel (c), we see where all the differences emerge: in the composition of ‘other’ costs. Interestingly, Cluster 2 nurseries make up nearly all of the transportation expenses. Cluster 3 nurseries spend more on water, which primarily reflects higher investments in improved water sources (as opposed to stagnant but free or cheaper water sources).

While it is unclear why this is, it may be that the UCDA requires them to transport their seedlings to collection points but directly procures from Cluster 3 nurseries.
To understand the economic viability of these different clusters, we combine measures of input usage and revenue to gauge overall profitability of these operations. As seen in panel (d) of Figure 3, Cluster 3 nurseries stand out as using more inputs and labour, but they earn lower profits according to our measured profit index. With all the standard caveats and potential problems with self-reported cost and revenue measures in mind, this pattern may suggest that in the current robusta CPMP, the additional investments made by Cluster 3 nurseries, which almost surely enhance the quality of the planting material they produce, do not generate additional profit for the operation. If this is true, the most likely explanation has to do with the rigid pricing scheme that the UCDA uses to procure seedlings from CNOs.

We find that 92 per cent of all seedlings sold to the UCDA/NAADS as part of the OWC distribution activities were sold at the standard price of 300 UGX per seedling. A few Cluster 3 CNOs claimed to receive prices of 500, 700, 1,000, 1,200 and 1,500 UGX for clonal cuttings, but these higher prices among a select few nurseries do not appear to offset the generally higher input

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24 Carefully constructing profit measures is a painstaking process that is beyond the scope of this study, so we aim instead to gauge the relative profitability of nurseries in the different clusters.

25 Since we are most interested in a measure of relative profits rather than the absolute profit level, we are most concerned with potentially systematic differences in self-reported costs and revenues across these three clusters. In particular, if Cluster 3 nurseries are more inclined to underreport revenues, then our comparison between clusters would be partly misleading. We acknowledge these concerns and, with these in mind, have strived to construct these profit measures as carefully and completely as possible.
Fig. 3. Heterogeneity in coffee production as reflected in cost and input composition and profitability by nursery cluster.
costs associated with better practices. If procurement prices are not sufficiently responsive to improvements in planting material quality, they may not enable these higher-quality nurseries to reap a return on investment in improved practices. The UCDA appears to have recently updated its stated procurement prices, as mentioned earlier, but there is not yet evidence that these stated prices will be implemented and offered to CNOs in a way that meaningfully enhances their incentives to invest in producing higher-quality planting material. This has important implications for incentives to innovate and retain value throughout the CPMP and clearly deserves more attention in follow-on research.

We have explored in detail the heterogeneity in observable characteristics and nursery structure and performance between these three distinct nursery clusters. It is clear from this analysis that Cluster 3 nurseries are very different than the other two clusters. Since Cluster 3 nurseries are more likely to turn out quality seedlings that retain more production potential than those produced by Cluster 1 and 2 nurseries, it is important to distinguish between two possible explanations for these systematic differences. First, it could be that these differences are evidence of nurseries and CNOs becoming more sophisticated and adopting better practices over time; after all, Cluster 3 nurseries are much older and more established than their counterparts. Second, it could be that these differences are due instead to a self-selection effect at the time these nurseries were established. For example, these differences may simply reflect the evolution of UCDA priorities as they recruited and trained different cohorts of CNOs. Cluster 3 CNOs may have been established when UCDA was actively recruiting would-be CNOs who were wealthier and better able to finance their nursery operations and to establish improved production practices, including establishing mother gardens. Since over 70 per cent of all seedlings in our sample are produced by Cluster 1 and 2 nurseries, deciphering between these two competing explanations is very important: if differences are due to learning and maturing over time, then perhaps the quality of material produced by Clusters 1 and 2 will steadily improve in the coming years.

If, however, differences are due to initial selection, then these observable differences may not improve naturally over time with experience in the nursery business—and quality improvements for the majority of seedlings in the official UCDA CPMP may be harder to come by. Our cross-sectional survey data do not allow us to analyse the evolution of Cluster 3 nurseries, so we cannot conduct a rigorous test of the learning and maturing explanation. We do see some evidence of time-invariant differences between these clusters (e.g. Cluster 3 CNOs have 2.5 years (25 per cent) more education than their Cluster 1 and 2 counterparts), which hints at the selection of CNOs into this cluster, but more careful adjudication of the self-selection explanation from the improvement-with-training explanation is beyond the scope of this paper.

4.4. Vertical integration and the emergency of ‘Cluster 4’ nurseries

While the vast majority of coffee planting material is produced and distributed via the CPMP described earlier and characterised in the preceding section, the
past 15 years or so has seen some important innovation in private nurseries that provide a high-quality alternative to the UCDA CPMP. These in-house nurseries for robusta coffee provide a stark contrast to the heterogeneity we explore using CNO survey data earlier. Whereas we identify three distinct clusters in the UCDA CPMP, the private in-house nurseries constitute a separate cluster altogether. For the purposes of this report, we refer to this set of high-quality nurseries as ‘Cluster 4’ nurseries but hasten to clarify that this cluster is not represented in our CNO survey data and therefore does not emerge from the above-mentioned cluster analysis. Instead, we describe two such vertically integrated firms using mainly qualitative, anecdotal information about the existence and structure of these nurseries. Specifically, building on the information provided in the AMA (2015) report, we directly contacted a selection of large coffee producers and exporters in Uganda with potential in-house nursery capacity to conduct brief interviews.

Firms emerge as a profitable organisational form when transactions costs make production, processing or service provision via market mechanisms, including contracts, prohibitively costly or inefficient (Coase, 1937). In such cases, a firm can find it profitable to internalise the transaction so that it need not rely on specialised market intermediaries for these inputs or services. This seems to describe very well the emergence of private, in-house coffee nurseries, especially in the wake of the CWD outbreak in the late 1990s. Large producers and exporters realised that there were considerable risks associated with (i) receiving inferior planting material or (ii) being unable to rely on consistent and timely access to good material from informal or small nurseries. Given the long-term investment riding on this planting material, there was simply too much riding on the vitality, vigour and resilience of the seedlings they transplanted to trust seedlings of unknown provenance, genetic potential and phytosanitary quality. From the perspective of these large, high-quality producers, this form of excessive transaction cost to procuring seedlings from the market became especially untenable when the NaCORI released the seven lines of CWD-r material. At that point, the risk of not benefiting from this material and being fully exposed to another CWD outbreak was unacceptable—and they opted instead to vertically integrate the propagation of planting material via private, in-house nurseries with CWD-r material procured directly from the NaCORI. For more details about the firms that constitute this ‘Cluster 4’, see Supplementary Appendix B.

4.5. Summary of results

Consider four key results. First, the CPMP in Uganda is subject to a host of constraints and challenges that characterise rural life in Uganda for the many actors in the pipeline between NaCORI and farmers, including the smallholder farmers themselves. These constraints and challenges make it difficult to retain the full value of potential production of coffee planting material. Remedies to these general constraints extend well beyond the specifics of the CPMP (e.g.
Second, the Coffee 2020 Plan initially prompted the UCDA to sacrifice quality of the planting material produced by nurseries in order to significantly expand the quantity of seedlings produced by the CPMP. This created significant new ‘leakage’ of production potential and seemed to jeopardise the productivity and resilience of smallholder coffee farmers in Uganda for decades to come. More recently, the Plan seems to have evolved to prioritise quality dimensions. Such a shift should be actively encouraged given the long-run implications for a perennial crop like coffee.

Third, adherence to best practices is low across all three CNO clusters we detect but is particularly low among the newer CNOs that were recently recruited and registered with the UCDA. These poor propagation practices likely compromise the vigour and phytosanitary health of seedlings. Only some nurseries are equipped to clonally propagate CWD-r cuttings from a mother garden. This explains why 95 per cent or more of the seedlings distributed via the UCDA are not CWD-r. This inferior germplasm in seedlings produced with poor practices limits future expected productivity by constraining positive $G \times E \times M$ interactions. While the expected present value of the seedlings produced in the current CPMP is therefore considerably lower than it might otherwise be, current changes to the implementation of the (now) 2030 Plan justify some hope for greater investment in quality planting material, particularly since we see suggestive evidence that UCDA priorities affect CNO investments and practices. In addition to directly shaping the structure of the CPMP via recruiting and training, the UCDA indirectly and importantly shapes the incentives to invest in quality and to innovate by the way it governs the pipeline, including its procurement prices and payment processes.

Finally, the highest-quality planting material in Uganda is produced outside the UCDA CPMP in private, in-house nurseries (i.e. Cluster 4). These nurseries seem to have emerged in the wake of the CWD outbreak of the late 1990s as firms realised the importance of consistent and timely access to high-quality, CWD-r planting material and vertically integrated to internalise these benefits. We know less about these Cluster 4 nurseries given that they are private and were not in our sample, but they seem to source CWD-r material directly from NaCORI and thereby retain as close to full production value as possible.

As a heuristic summary of these key insights, we offer Figure 4. This diagram abstracts from some of the complexity of the CPMP as we have described it in this report but captures essential elements of the heterogeneity in the capacity of CNOs along the pipeline. While the dominant pattern in the Uganda coffee sector suggests that the vast majority of planting material that is currently flooding areas with a history of or potential for coffee cultivation is inferior quality and CWD susceptible, there are nevertheless some encouraging signs that coffee policy and institutions are aware of some of these quality leaks and may be interested in fixing a few of them.
Fig. 4. Heuristic summary of results depicts the heterogeneity in CPMP and associated implications for farm-level planting material quality. Planting material in the CPMP flows from left-to-right beginning with robusta coffee lines developed by the NaCORI (left) and ending up in production as coffee trees of varying quality (right). Vertical height of each box is approximately proportional to the expected quantity of planting material flowing through these points along the pipeline.

5. Prospects and opportunities

Innovation demands investment—and the CPMP in Uganda is no exception: real investments of resources will be required to upgrade the CPMP to (i) generate higher potential production value at the upstream plant breeding stages and (ii) retain more of this production value as the material is propagated and multiplied and ultimately delivered to farmers as robusta seedlings. It is important to recognise, however, that the current CPMP also entails significant investments in resources, but these investments have increasingly been aimed at scaling up the volume of seedlings produced rather than their quality.

There are existing resources in the current CPMP that might be allocated differently to more directly incentivise innovation and to amplify the return on investment in upstream innovation. To illustrate, Table 2 shows a simple “budget neutral” counterfactual based on 2016 procurement numbers: How much more could UCDA offer for coffee seedlings if it improved the rate of survival-to-transplanting from 36 to 85 per cent through improved management and timing of the distribution process? Under this scenario, they could more than double the price offered to CNOs and thereby incentivise investments in higher quality planting material. Beyond more efficient use of existing
resources, serious upgrades in the CPMP will demand substantial new investments in improved practices. We find some evidence that the Cluster 3 CNOs are investing their own resources in improved production practices in general but did not discover specific cases of true innovation on their part. This is not entirely surprising given that the UCDA is the intermediary for the vast majority of the planting material emerging from the official UCDA CPMP. This appears to leave little room for market incentives to produce high-quality planting material to transmit directly to CNOs (although the recently announced prices for improved seedlings may improve these incentives).

The most striking evidence of innovation in the propagation of planting material instead comes from the ‘Cluster 4’ private nurseries that almost surely produce the most uniformly high-quality seedlings in Uganda. Tellingly, these nurseries have emerged where vertically integrated firms have fully internalised their return on investments in improved practices. Outside of these in-house nurseries, there appears to be only weak incentives at best for CNOs to make similar investments. Consequently, there are two distinct and parallel futures for Ugandan robusta coffee: farmers fortunate enough to have access to ‘Cluster 4’ seedlings are investing in quite a different productivity future as coffee farmers than their counterparts who rely on the UCDA CPMP. Because they are working with higher potential material from the time of transplanting, these fortunate farmers are more likely to invest in coffee production for the
life of the tree due to productivity synergies in inputs (i.e. high-quality initial inputs raise the returns on subsequent high-quality inputs).

The presence and success of ‘Cluster 4’ nurseries in Uganda will continue to shape the ongoing dynamics of the CPMP, including any attempts to upgrade this pipeline. Consider two extreme paths that might emanate from these ‘Cluster 4’ nurseries in the coming decade. First, the official UCDA CPMP may continue to function independently of the more advanced ‘Cluster 4.’ Second, ‘Cluster 4’ nurseries may scale up rapidly and outcompete the existing UCDA CPMP on quality terms. The first seems far more likely than the second. There is simply very little evidence that ‘Cluster 4’ nurseries aspire to dominating the planting material pipeline. This likely path raises upgrading opportunities and provides a few clear policy recommendations. First, demonstrated successes in ‘Cluster 4’ offer valuable opportunities to learn how to upgrade the UCDA CPMP. Such demonstration effects are likely to be especially powerful among the more capable and more entrepreneurial Cluster 3 CNOs. These learning spillovers need not be confined to technical aspects of nursery management; much could be learned from these private nurseries about the form and level of incentives needed to instigate UCDA CNOs to upgrade their practices and investments, including access to higher procurement prices for higher-quality material. Second, there are surely opportunities to engage ‘Cluster 4’ firms and other service providers more directly in the CPMP via private–public partnerships. The UCDA already sources some material from these nurseries, but more could be done to aggressively and strategically leverage this capacity to upgrade the public CPMP as described more later. Finally, ‘Cluster 4’ has succeeded in large part by internalising the benefits of high-quality planting material via vertical integration. The UCDA should explore ways to replicate these successes through enhanced property rights along the CPMP, including operationalizing the Plant Variety Protection legislation passed in 2014.

In order to induce greater investments in upgrading the CPMP in order to tap the full potential of upstream innovation and to incentivise further innovation investments, it is critical to improve the transmission of information about planting material quality to farmers and other actors in the pipeline. While the UCDA presently conducts periodic inspections of registered CNOs, there is a real need for independent and rigorous verification of propagation conditions. Such services have been launched elsewhere in the agricultural inputs sector in Uganda. The UCDA should issue a request for proposals from the firms that offer these services as a way to explore possibilities for independent verification and certification to increase farmers’ confidence that their planting material is high-quality, CWD-r that is worth their time and investments. Relatedly, DNA fingerprinting technologies and techniques are advancing quickly. It may soon be possible to cost-effectively determine key genetic features of

26 Despite repeated requests, we were unable to learn the details of these inspections.
27 For example, AgVerify aimed to provide such verification services with other crops, but ultimately shutdown—ostensibly due to resistance from entrenched interests.
both seedlings and established coffee trees. Conducting a representative inventory of these traits should be a top priority, and the possibility of continued monitoring with DNA fingerprinting tests might provide greater incentives for compliance with best propagation practices. These tests may be particularly useful as UCDA introduces a multi-price menu for procuring seedlings from CNOs.

To further incentivise investments in the CPMP and in upstream innovation, the UCDA could experiment with new ways of educating smallholder farmers and giving them greater choice and greater influence over CNOs. Among such ‘demand pull’ options are improved agricultural extension and a voucher system that gives farmers greater voice in the CPMP. In order to reap the benefits of upgrading the CPMP, farmers must be more aware of quality and understand why they should be more discriminating when choosing planting material. In this sense, an effective agricultural extension system for coffee farmers is a critical component to upgrading the CPMP as a means to stimulating demand of quality planting material. To give farmers greater choice over material, the UCDA should consider piloting a voucher system for seedlings in which farmers can choose whether to receive generic UCDA seedlings as usual or to receive vouchers that directly subsidise their purchase of seedlings from CNOs. This would enable farmers to self-select into the market for higher-quality seedlings and would incentivise the more entrepreneurial and innovative CNOs to respond with better seedlings and new ways of signalling quality to their customers. These CNOs might quickly realise how much they could learn from the ‘Cluster 4’ nurseries about producing the highest-quality planting material. Voucher systems can be challenging to implement, but the time is ripe for modest experimentation with pilots to incentivise greater investment as Uganda aims for 20 million bags produced in 2030. While it is unclear how the recent and controversial agreement to give an Italian company exclusive rights to export Uganda coffee will shape the future of the CPMP, at very least it signals a willingness to think big and experiment with coffee. For the success of these endeavours, we hope these ambitions soon give planting material quality the attention and investment it deserves.

Acknowledgements

G.D., who played a central role in this research and was a wonderful co-author, collaborator and friend, tragically passed away just before this paper was accepted for publication. The study was part of the Project on Intellectual Property and Socio-Economic Development under the World Intellectual Property Organization (WIPO) Committee on Development and Intellectual Property and has benefitted from feedback, authorization and support of the Ugandan National Council on Science and Technology (UNCST) and the Uganda Registration Services Bureau (URSB) (see also Lybbert et al., 2017). Julius Ecuru, Assistant Executive Secretary, UNCST, acted as the Ugandan government counterpart as did various representatives of the URSB. Pierre Mohnen provided input as an official reviewer. This analysis and the original background
paper benefited from the contributions and research assistance of Samuel Bird, Jack Gregory and Oscar Barriga Cabanillas (PhD students, UC, Davis). Several others contributed directly to this research, including Research Assistants at Makerere University Sarah Mirembe, Diana Namwanje and Kwagala Innocent, WIPO research assistant Kritika Saxena, UC Davis research assistants Amanda Gilchrist and Alicia Hsiao and participants at an October 2016 ‘Planning Workshop’ and a follow-up ‘Validation Workshop’ in December 2017 both convened by UNCST and WIPO. The coffee study benefited from the expertise and insights of Emma Joynson-Hicks and Martin Fowler. We thank anonymous reviewers and the editor for critical feedback and suggestions.

**Supplementary data**

Supplementary data are available at ERAE online.

**References**


